PB81-157794

Acid Rain

(U.S.) Environmental Protection Agency
Washington, DC

Jul 80

U.S. Department of Commerce
National Technical Information Service
NTIS.

EPA

United States
Environmental Protection
Agency

Washington, D.C. 20460

EPA-600/9-79-036
July 1980

Office of Research and Development

PB81-157794

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REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

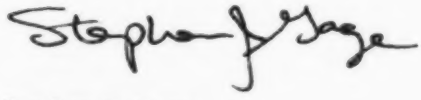
FOREWORD

Acid precipitation has become one of the major environmental problems of this decade. It is a challenge to scientists throughout the world. Researchers from such diverse disciplines as plant pathology, soil science, bacteriology, meteorology and engineering are investigating different aspects of acid precipitation.

What has this research shown? We know that acid rain can damage property, fish, soil and some crops. We know that most acids in precipitation are sulfuric and nitric acids. We know that these acids can form in the atmosphere from substances emitted as a result of fossil fuel combustion. We know that such substances can travel hundreds of miles from source to deposition. And we know that our fossil fuel power plants, industries and motor vehicles emit large amounts of acid-forming pollutants. We do not, however, understand exactly how these processes work. EPA's research program, in conjunction with those of several other agencies, is attempting to find answers to these questions.

Despite some unknowns, the preponderance of our evidence to date points to the need to control the emissions of acid-forming sulfur and nitrogen compounds. Given the potential for damage from acid precipitation, prudence dictates that we act soon to avoid far more serious problems in the future. EPA's regulatory standards for new power plants and motor vehicles are a major step in the right direction. Further steps may be required in the near future.

This background document tells what we know — and don't know — about acid precipitation. I hope you'll find it both informative and interesting.



Stephen J. Gage
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for Research and Development

ACID RAIN

INTRODUCTION

Mankind has always valued the rain. Plentiful and timely rains assure good crops and abundant water supplies. Summer rains are refreshing. Spring rains help recharge aquifers and cleanse groundwaters; autumn rains and winter snow cleanse the air. With rain comes a sense of hope, vitality and a promise of the future.

Over the last decades, however, in many areas of the nation and the world, simple rainfall has taken on a new and threatening complexity. In these locales the rain is no longer benign, for here the rain must pass through an atmosphere polluted with sulfur oxides and nitrogen oxides. Such atmospheric oxides do occur naturally and have, in past partnership with the rain, become part of nature's balance to help nourish plants and aquatic life. But it is the oxides from the unnatural sources—man-made industries, power plants, auto exhausts and other fossil fuel combustion processes—that have disrupted that partnership and upset the balance. The falling rain and snow now react with the oxide pollutants to produce precipitation of new chemical properties, often a mixture of sulfuric acid, nitric acid and water, a far cry from "pure rain" or "clean snow." It has become acid precipitation—acid rain.

There is so much acid in some rains that they do not meet Environmental Protection Agency (EPA) water quality criteria for aquatic life. Moreover, acid rain is a problem with national and international ramifications as clouds of pollution drift between cities, states, countries and continents, on the way to becoming acid rain.

We know much about acid rain. We know that fish die or don't reproduce when water is too acidic. We know about air transport patterns and about the major sources of air pollution. We are beginning to understand how plants and man-made materials respond to acid rain. But key questions remain to be answered, key pieces of the acid rain puzzle are yet to be solved. Overall we need to be able to tie the existing information to future data to form a consistent, comprehensive, scientific description of the causes, consequences and means to control acid rain.

Acid rain. While the name itself evokes concern, the term is a misnomer of sorts because it excludes other means whereby acids fall to earth; there is acid snow, acid sleet and hail, even cases of acid fog. And there is another phenomenon: pollutants in dry form fall to earth awaiting some future precipitation or other moisture that may transform them into the same acids found in acid rain. Both of these phenomena, precipitation and dry deposition, are part of the same problem which—rightly named—is acid deposition. Nevertheless, acid rain is the name by which the problem is identified.

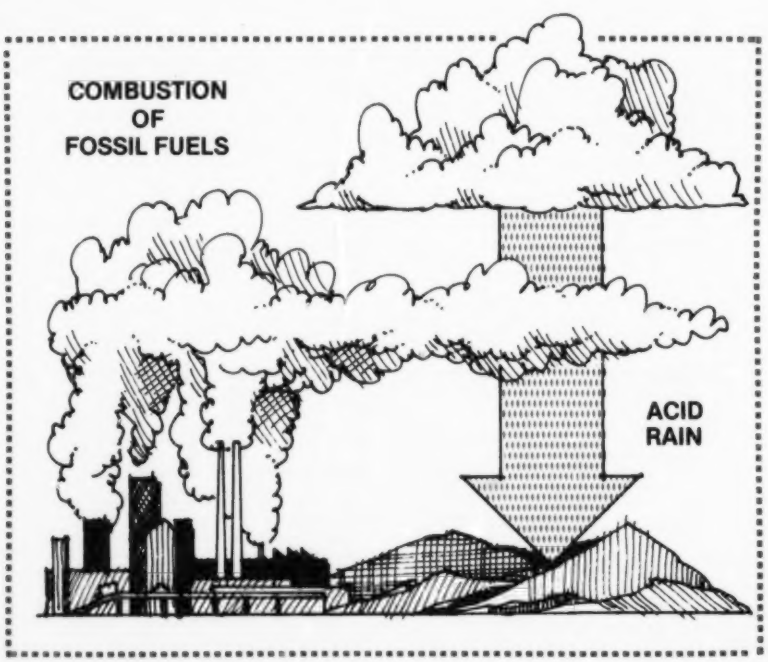
Acid rain is an issue that is currently of concern to many government agencies and private businesses. The Department of Agriculture, the Forest Service and the Fish and Wildlife Service are studying, respectively, acid effects on crops, trees, and fish and wildlife; the Geological Survey is trying to determine the effects on water quality and the Department of Commerce is studying acid rain effects on materials. The Department of Energy is involved

with the problem because the acids are products of energy production; the automobile industry and the electric power industry are vitally concerned because sulfur oxides and nitrogen oxides are put into the air by smoke stacks and auto exhausts. And at EPA all of these effects are of interest because of our mandate to protect the environment and the health and welfare of people.

This report is a gathering of what is known about acid rain. It does not contain the complete answer because our understanding of acid rain and its effects is still in its formative stages. It is EPA's intent to enlarge and expand upon this body of knowledge and to help provide the data and technology necessary to protect the quality and productivity of our environment. In short, EPA is determined to help define, avert, and solve the problems that surround the acid rain phenomenon.

ACID RAIN: THE FACTS

Rain tends to be naturally acidic because carbon dioxide in the atmosphere reacts with rain to produce carbonic acid. That amount of acidity is, however, sufficient to dissolve minerals in the Earth's crust, making them available to plant and animal life, yet not acidic enough to cause damage. Other atmospheric substances from volcanic eruptions, forest fires, and similar natural phenomena also contribute to the natural sources of acidity in rain. Still, even with the enormous amounts of acids created annually by nature, normal rainfall is able to assimilate them to the point where they cause little, if any, known damage. It is mankind's contribution, however, that is thought to throw off this acid balance and convert natural and mildly acidic rain into precipitation with far-reaching environmental effects.

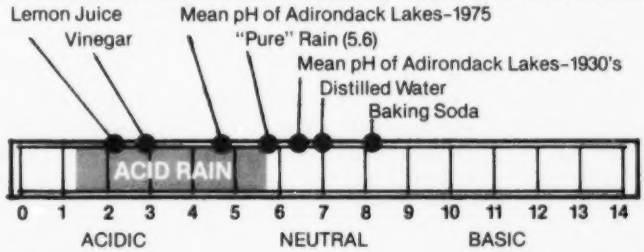


Measuring Acid Rain

The acidity of any solution, including rain or snow, is measured on a scale known as a pH scale. This scale is numbered from 0 to 14. A pH value of 7 is neutral, neither acidic nor alkaline. Values lower than 7 are more acidic—vinegar, for instance, with a pH of between 2.4 and 3.4. Values above 7, such as for ammonia or lye, represent alkalinity.

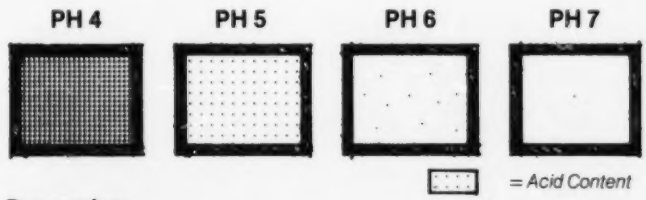
The pH scale is a logarithmic measure, that is, each change of one pH unit—say from 6 to 5—represents a *tenfold* increase in acidity. Thus a drop from pH 6 to pH 4 represents a hundredfold increase and drop from pH 6 to pH 3 represents a thousandfold increase in acidity.

For rain or snow, acidity measurements reflect the balance of positive and negative ions in the precipitation (see box). The ions can come from a variety of compounds or elements (sulfur and nitrogen oxides, hydrogen, carbon oxides, chlorine etc.) thus the total acidity of precipitation must take into account all of the sources of ions.



The pH Scale

The pH ("potential hydrogen") scale is a measure of hydrogen ion concentration. Hydrogen ions have a positive electrical charge and are called cations; ions with a negative electrical charge are known as anions. A substance containing equal concentrations of cations and anions so that the electrical charges balance is neutral and has a pH of 7. However, a substance with more hydrogen ions than anions is acidic and has a pH less than 7; substances with more anions than cations are alkaline and have pH measures above 7. Thus, as the concentration of hydrogen ions increases, the pH decreases. But the pH scale says nothing about whether the cations or anions are from natural or manmade sources; a hydrogen ion from an industrial smokestack measures the same on the scale as a hydrogen ion from natural minerals.



Remember

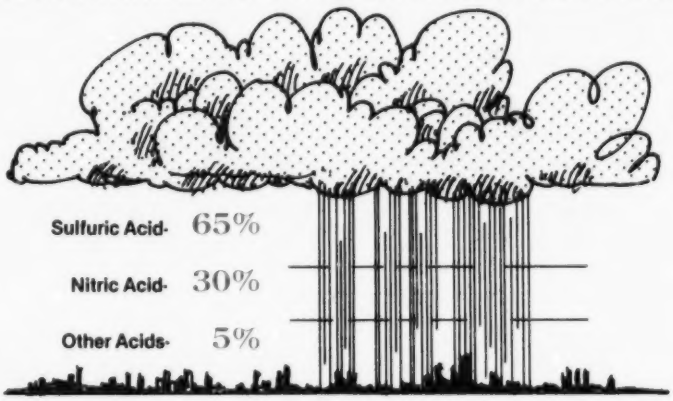
The *lower* the pH value, the *higher* the acid content. Each full pH unit *drop* represents a *tenfold* increase in acidity.

Pure Rain

"Pure" rain is defined as rain with a pH of between 5.6 and 5.7. These pH values take into consideration the amount of acidity created by the reaction of rainwater with normal levels of atmospheric carbon dioxide. But the acid precipitation that is of concern in this report is that rain (or snow, sleet, or hail) with a pH of 5.6 or below.

This concern with acid rain is not without good reason. Recent research shows that the average precipitation in most states east of the Mississippi River lies between pH 4 and 5, with individual storms having pH values well below these averages. Furthermore, acid rains and snows have been observed in remote and wilderness areas in both the eastern and western United States testifying to the possible widespread dispersion of the phenomenon.

The questions are then: What are the hazards posed by an acid rainfall? Who and what is threatened by it? What is necessary to control it? And, how can control be accomplished?



TYPICAL NORTHEASTERN U.S. ACID RAIN COMPONENTS

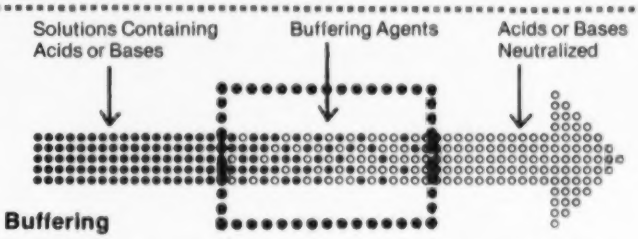
The Acids in Acid Rain

In the eastern United States, the major component of acid rain is sulfuric acid, comprising as much as 65 to 70% of the rain's acidity. The second major component is nitric acid with a presence of 25 to 30%; other acidity comes from other acids in trace amounts. In the western United States, the acids in acid rains are generally half nitric acid and half sulfuric acid, although in some western urban areas, as much as 80% of a rain's acidity can be comprised of nitric acid. In either case, west or east, the major components do not start in the atmosphere as acids. Rather, they generally begin as sulfur oxides (SO_x) and nitrogen oxides (NO_x)—gases emitted into the air primarily from fossil fuel combustion in power plants, industry, and cars and trucks.

In the atmosphere, SO_x and NO_x—widely recognized as among the major man-made pollutants—are transformed into sulfates and nitrates, which then react with moisture in the air, forming acids. Thus when it rains, it rains a solution of water and sulfuric and nitric acid.

When Acid Rain Falls

Rain and snow as it falls through the atmosphere functions as an air cleaner. When there is a long interval between rains, sulfates and nitrates can accumulate in large stagnant air masses, making the eventual precipitation highly acidic. Under certain conditions, these compounds may be buffered by airborne alkaline particles. However, while such atmospheric buffering is sometimes significant (two-thirds of the atmospheric sulfates in Minnesota and Scandinavia are estimated to be neutralized in this manner), usually it cannot nearly counter the acid-forming compounds downwind of heavily polluted areas.



Buffering

A substance has *buffering* capabilities when, coming into contact with a solution that contains acids or bases, it neutralizes the acids or bases without appreciably changing its own nature.

Normal rainwater (pH 5.6) is not highly buffered and therefore is susceptible to pH decreases.

Airborne alkaline particles sometimes buffer air pollutants. Soils, on the other hand, can have an enormous buffering capacity.

These accumulation, dispersion, and neutralization phenomena help cause seasonal differences in the acid deposition problem. During the summer months, air circulation is generally slow, with a decrease in the dispersion and dilution of atmospheric acids. Increases in automobile use and electrical generation to operate air conditioners result in a high level of fossil fuel combustion. Also, increased solar radiation and humidity combine to speed the process that turns SO_x in the air into sulfuric acid. Nitric acid levels are also affected, but significantly less so, making the acid in the summer rains more rich in sulfuric acid than at other times. The result? Summer rains may be the most acidic.

Even so, there is not always a correlation between the pH of a rainfall on a given day, and the potential it has for damage to the environment. In cold climates, for example, acid substances from acid snow can accumulate in the winter snowpack; thus, when the snowpack melts in the spring, a winter-long buildup of acids courses through soils, vegetation and surface waters. This type of deferred release of acids over and above the gradual accumulation of acids in streams and lakes can be particularly devastating, especially in the spring. Reproductive cycles can be interrupted or thwarted, seed germination can be retarded and newly-hatched fish fingerlings or other new life can be destroyed. The implications for forestry growth, farm productivity or deciduous plant vigor are of particular concern.

From Here to There —The Transport of Acid Rain

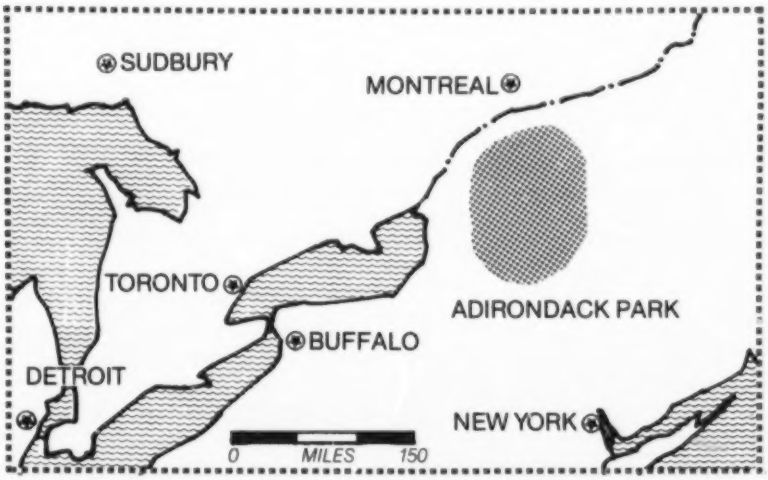
Once the SO_x and NO_x compounds are released into the atmosphere, two factors determine their geographic impact. First is their *residence time*—the amount of time before the compounds either descend to the earth as dry deposition or react with moisture in the air to form acids or other concoctions. Second is the *distance* the sulfates and nitrates can travel in that time.

The residence time of sulfates and nitrates is generally up to about four days, although they may remain aloft longer. Their movement depends primarily on wind speeds. Under certain conditions sulfate and nitrate compounds can stay aloft long enough to cross continents, oceans, and international boundaries, creating a situation in which the acid rain in one country is caused by the emissions of another, but the recipient of this damaging rain receives little or no benefit from the source initiating the pollution.

For example, in 1892, the New York State Legislature established New York's scenic Adirondack Park as "forever wild." But in the 1950s, fishermen began to complain of fewer and fewer trout in the park's more than 200 high lakes and streams. It was then thought that predator yellow perch were responsible, but soon the perch died out as well, as did new species introduced experimentally to replace the native fish. For a while, beavers and the logging industry bore the blame. It was not until recently, however, that scientists discovered that the chief reason for the disappearance of fish from half of the park's high elevation lakes was acidification of the lake's water.

The acid rain condition in the "forever wild" Adirondacks underlines the problem posed by the transport of pollutants from the point of their creation to the point of their effect. Clearly this is a problem that cannot be dealt with on a local level, and in instances where the polluted atmosphere drifts across international borders, not even stringent national controls can stave off potentially severe damage.

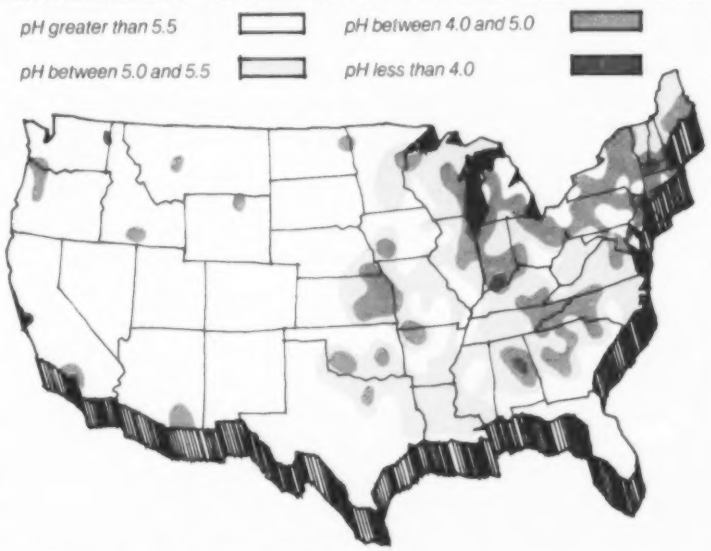
It is the Adirondack's geographic misfortune that they lie downwind of many large industrial areas; it is similarly Sweden and Norway's misfortune to suffer the airborne pollution from England and Germany. In a few short days and often less, problems of local origins become ones of international scope.



Eastern Rain/ Western Rain

The region of the continental United States most affected by acid rain is the Northeast, where pH levels of between 4.0 and 4.5 are commonplace. In recent studies, New York City averaged a pH of 4.28; the Hubbard Brook Experimental Forest in New Hampshire, a pH of 4.03; and in numerous areas in the mountains of Pennsylvania, New York, and New Hampshire, pH values ranged from 3.98 to 4.02. Specific individual storms with pH levels of anywhere between 3.0 and 4.0 are not out of the ordinary, and values less than 3.0 have been found.

Notably, the most rapid increase in acid precipitation in the country seems to be in the Southeast, an increase paralleling the expansion of Southeastern urban and industrial acitivities that result in sulfur and nitrogen emissions. Here the trend is more apparent than in the Northeast because the atmosphere in the Southeast is just beginning to deteriorate and fewer acids are required to cause a pH change. In 1979, four rains in North Carolina were measured at pH 3.3.



Bringing It All Back Home

In March, 1973, thousands of school children across the country participated in an exercise to discover the pH levels of rainwater and snow in their own area. The results of this study and the map generated from their data reveal the following:

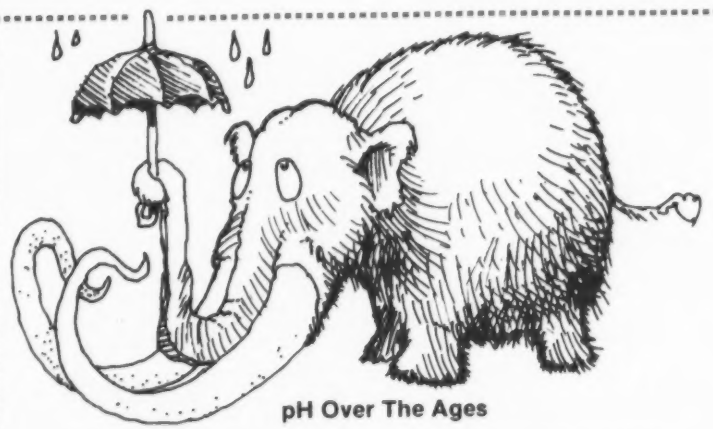
- the entire half of the country east of the Mississippi had precipitation of pH 5.0 to 5.5;
- many pockets east of the Mississippi have precipitation with a pH of between 4.0 to 5.0;
- west of the Mississippi there are also a number of pockets with precipitation values of between pH 4.0 and 5.0.

While the study was not scientifically rigorous, it did serve to support what acid rain watchers have documented.

West of the Mississippi, rains are generally neutral or even alkaline. Colorado, the Los Angeles Basin, the San Francisco Bay Area, Spokane, Tucson, and Portland are the known exceptions. In these locations, as in the Northeast, precipitation ranges from between pH 4.0 to 5.0. A recently completed two-year study in Southern California showed the mean pH in Pasadena to be 3.9. Most of this is thought to be due to nitric acid contributed by automobiles and trucks.

THE HISTORY OF ACID RAIN

The earliest known measurement of precipitation pH in the United States was done in Brooklin, Maine, in 1939 when a pH value of 5.9 was obtained during a single rainstorm. Ten years later, during a 1949 summer rainfall in Washington, D.C., measurement of the pH of eight individual raindrops established their mean pH value to be 4.2.



pH Over The Ages

The pH of precipitation found preserved in glaciers and continental ice sheets has been shown to be generally above 5.

In Greenland, ice that originated as snow 180 years ago had a pH ranging from 6 to 7.6.

Decade of Transition

Although pH levels were not reported until the late '50s, precipitation data indicate that by mid-decade the rain in the eastern United States had turned decidedly acidic. During the early '50s, a number of key developments took place that brought this about.

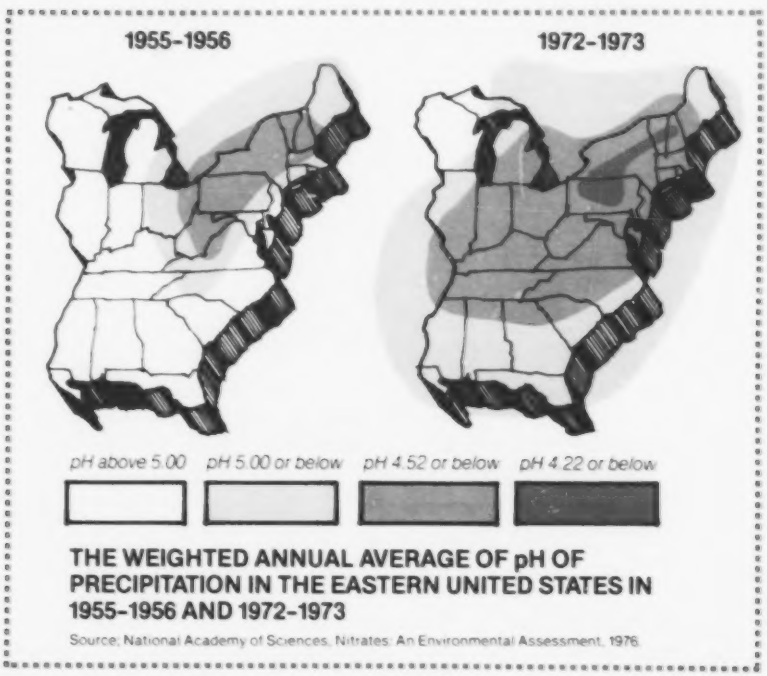
First, there was an increased amount of fossil fuel combustion as more electricity was generated, more automobiles were on the road and more factories were built.

Second, in the past 30 years smokestack heights have increased along with the size of the plants thereby putting pollutants higher into the air. This permitted the pollutants to remain aloft longer which, in turn, led to wider pollution dispersion. The local problems were abated; regional problems were intensified.

And third, summertime atmospheric acid concentrations in some regions became greater than winter concentrations, due primarily, it is thought, to more power plant emissions and to automobile exhausts.

It was not actually until the early 1970s, however, that the Hubbard Brook Ecosystem Study indicated the acid precipitation problem in North America. As a result, in the years that followed, the sparse data gathered in the '50s and '60s were studied with new interest. The first complete set of data on the pH of precipitation for the entire United States was collected between 1959 and 1966 by the U.S. Public Health Service and the National Center for Atmospheric Research. These findings indicated pH levels of well over 7 in the western United States compared to levels of less than 4 in New England; overall, eastern rains were shown to be surprisingly acidic.

In the 1970s, pH readings showed that acid precipitation had become commonplace throughout the eastern United States. Consistently low pH readings of precipitation in rural New England, hundreds of miles from urban industrial centers, were testimony to the long-range transport of SO_x and NO_x.

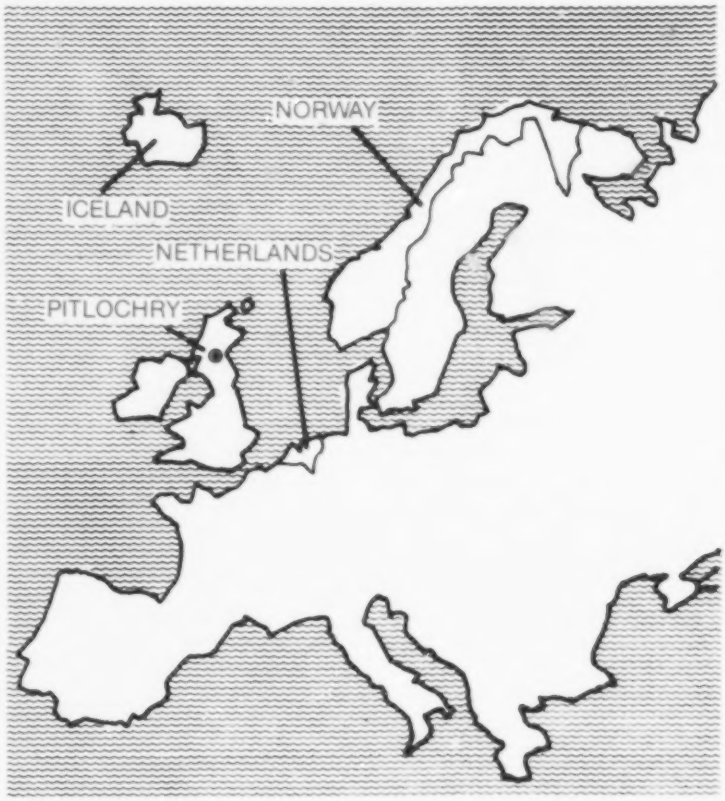


THE WEIGHTED ANNUAL AVERAGE OF pH OF PRECIPITATION IN THE EASTERN UNITED STATES IN 1955–1956 AND 1972–1973

Source: National Academy of Sciences, Nitrates: An Environmental Assessment, 1976.

UNDERSTANDING ACID RAIN EFFECTS

Data from an air pollution monitoring network in Europe provided the first evidence of a regional acid rain problem. Gradually, over the years from 1968 to the present, scientists first in Europe then later in Canada and the United States came to recognize that a number of key factors influenced the times and places that acid deposition would have important effects. The recognized factors include—climate, topography, geology, biota and human activity.



In Europe . . .

The lowest recorded pH value for an individual storm was 2.4 on April 10, 1974 at Pitlochry, Scotland. During that same April a value of of 2.7 was reported in Norway and 3.5 in Iceland.

In 1967, a survey in the Netherlands reported the lowest annual pH level--3.78.

FACTOR: Climate

The most important aspect of climate in estimating the potential effects of acid rain is the amount and frequency of precipitation i.e., number of days of rainfall and number of inches of rain per year. In drier climates, such as the western United States, windblown alkaline dust is abundant and tends to neutralize atmospheric acidity. In humid climates, like the Eastern Seaboard, less dust is in the air, and precipitation tends to be more acid. Seasonal timing of rain and snowfall is also a key element in the measure of potential acid precipitation effects. For example, large doses of acids during fish spawning or seed germination may have more significant effects than the same doses at some less critical time.

Wind direction and wind speed determine the direction and the speed pollutants travel, and to some exteat, exert control over their dispersion and dilution. Humidity and solar radiation influence the speed at which gases convert to acids.

FACTOR: Topography/Geology

The topography of an area, taken along with its geology, has a marked influence on acid rain effects. Areas most sensitive to acid precipitation are those with hard, crystalline bedrock and very thin surface soils. Here, in the absence of the buffering properties of soil, acid rains will have direct access to surface waters and their delicate ecosystems. Conversely, a thick soil mantle or one with a high buffering capacity helps keep acid rain damage down. Mountainous areas generally have thin surface soils; flatlands rarely do.

The location of bodies of water is also a consideration, with headwater lakes and streams especially vulnerable to acidification. Lake depth, the ratio of watershed area to lake area, and the residence time of water in lakes all play a part in determining the consequent threat posed by acids. The source of the acid (rains or runoff) may also influence effects.

FACTOR: Biota

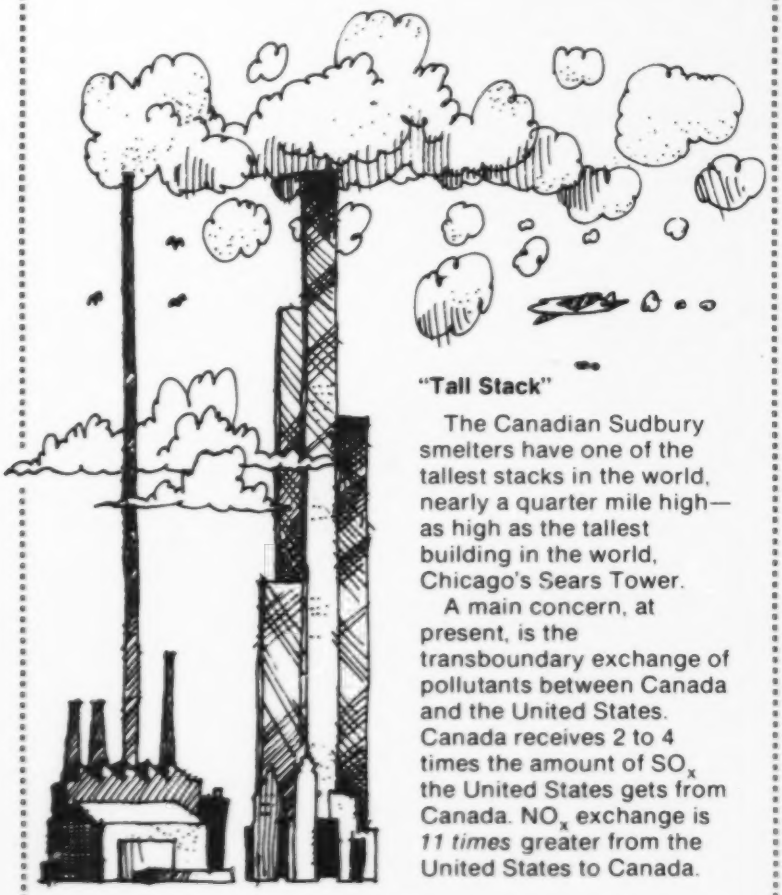
The kinds of trees and plants in an area, their height, and whether they are deciduous or evergreen may all play a part in the potential effects of acid rain. Without a dense leaf canopy, more acids may reach the earth to impact on soil and water chemistries. Stresses on the plants will also affect the balance of local ecosystems. Additionally, the rate at which different types of plants carry on their normal life processes influences an area's ratio of precipitation to evaporation. In locales with high evaporation rates, acids will concentrate on leaf surfaces. Another factor is that leaf litter decomposition may add to the acidity of the soil due to normal biological actions.

FACTOR: Human Activity

Any discussion of acid rain effects would be incomplete without considering the chief pollution sources—automobiles, smokestacks, and other emitters of the by-products of fossil fuel combustion. And a number of questions about these issues must be posed. What type of fuel is being used? Is it high in sulfur content? Does the type of combustion enhance or retard formation of NO_x?

Generally speaking, the more fuel that is burned, the greater the amount of pollutants discharged to the air and the more severe the potential effects of acid rain.

Questions must also be asked about what types of pollution controls are being employed. Cleaned coal? Low-sulfur coal? Exhaust gas cleaners (scrubbers)? Catalytic converters? While controls are effective in reducing the amount or concentration of emissions, other means of addressing local pollution problems, such as tall stacks, also determine the nature of remaining exhausts. For example, tall stacks may discharge the same amount of emissions as small stacks but, due to the stack height, emissions remain aloft longer. Longer airborne times may be more conducive to the spread of acid deposition. The tall stacks—400 to 1200 feet tall—now number more than 200 in the United States.



"Tall Stack"

The Canadian Sudbury smelters have one of the tallest stacks in the world, nearly a quarter mile high—as high as the tallest building in the world, Chicago's Sears Tower.

A main concern, at present, is the transboundary exchange of pollutants between Canada and the United States. Canada receives 2 to 4 times the amount of SO_x the United States gets from Canada. NO_x exchange is *11 times* greater from the United States to Canada.

Other questions to be posed involve location and size of urban and industrial developments. How large and concentrated are these settlements? Are they upwind or downwind from delicate ecosystems or regions with little buffering capacity? Which way does the wind usually blow? At what time of year are most pollutants emitted? Unfortunately, the answers to these questions generally are the "wrong" ones when addressing the problem of man's contribution to the effects of acid precipitation; urban and industrial areas are often large and concentrated, many are upwind from sensitive regions, and summer is when emissions are at their peak.

But not all of man's activities worsen the effects of acid rain. Use of low-sulfur coal and installation of stack scrubbers help reduce pollution emissions. Certain agricultural activities also help ameliorate the potentially harmful effects of the rain. Limed fields will buffer the rain, and dustfall from windblown soil can neutralize acids in the air. On the balance, however, the human contribution to acid rain effects is a substantial increase in the intensity and spread of effects.

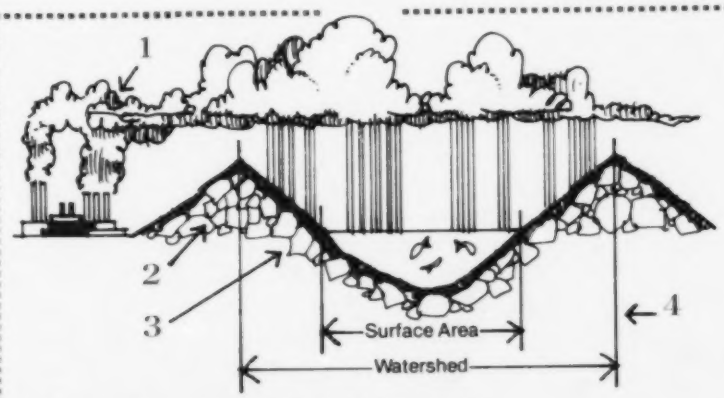
THE DAMAGES DUE TO ACID RAINFALL

Strange things have been happening. In the Adirondacks many lakes no longer hold fish. In some cities, statues, centuries old, lose their features. Tombstones in New England have become illegible. In Sweden lakes turn a swimming-pool blue—almost all their organic life erased. In parts of Pennsylvania and North Carolina automobile finishes rapidly corrode. Some house paints last only a few years.

The effects of acid rain are as pervasive as the rain itself with water, fish, vegetation, stone, steel, paint, soil, and mankind all affected to a greater or lesser degree. Exactly what are these effects? And how extensive are they? As is the case with many environmental problems, there are no easy answers to these questions.

Effects on Aquatic Ecosystems

It is in lakes or streams where the most dramatic effects of acid rain have been clearly observed. It is known that low pH precipitation can kill—fish eggs, salamander eggs, frog eggs—entire lakes and streams can be put under stress, devastated, or destroyed. Fish-food organisms are affected, causing not only the demise of a lake or stream, but also the disappearance of the animals that depended on the water body for sustenance. The extent of change in acidity of a lake or stream is determined mainly by the buffering capacity of the surrounding soil and the composition and size of the watershed in which the water resides. If the watershed soil is alkaline—containing limestone or bicarbonate to neutralize incoming acids—the lakes and streams will be acidified less rapidly and the aquatic community will be far less susceptible to harm.



Lakes Most Susceptible to Acidification

1—are located downwind, sometimes hundreds of miles downwind, from major pollution sources—electricity generation, metal refining operations, heavy industry, large population centers

2—are surrounded by hard, insoluble bedrock with thin, sandy, infertile soil

3—have low buffering capacity due to the terrain

4—have a low watershed to lake surface area ratio

The Fish Population. Fishing is one of the major reasons many people visit lakes and streams, thus changes in fish populations are among the most obvious effects of acid precipitation. In Norway, for example, poor catches of salmon were reported as early as the turn of the century, with precipitous declines in catches observed since the mid 1960's. These declines are now recognized to have been largely caused by acid precipitation. Today, the salmon catch in the country's highly acid southern rivers is practically nil, and an overall decline of various species has been observed in many Norwegian lakes and rivers.

On Sweden's west coast, 50% of the lakes have pH values of less than 6.0, a decrease of almost 2.0 pH units since the 1930s. Overall, 10,000 lakes have been acidified to a pH below 6.0 and 5,000 to a pH below 5.0. Salmon populations in western Sweden have been decimated, and in the central and eastern sections of the country, other sport fish have been seriously affected.

Technician sampling lake water for pH levels

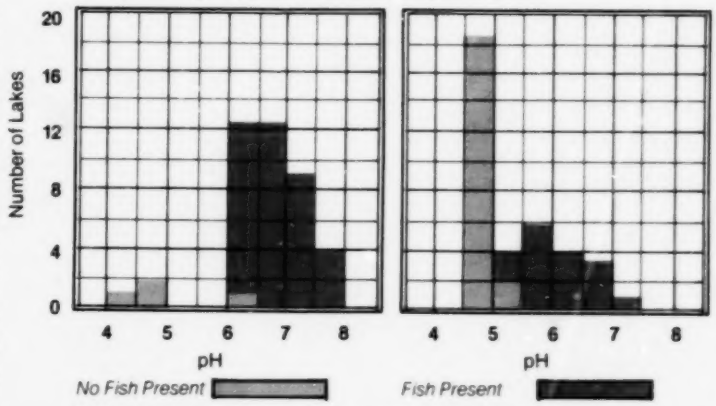
Add Lime

The addition of lime to acidified lake ecosystems has met with some beneficial results. In Scandanavia chalk added to Swedish lakes has led to increased phytoplankton growth and improved fish survival. Adding $CaCO_3$ and $Ca(OH)_2$ to two acidic lakes in Sudbury, Ontario increased pH, decreased heavy metal concentrations and caused a temporary decline in chlorophyll. Liming experiments in Norway, however, indicate that this practice would only be feasible for small ponds and streams.

The first North American studies linking lake acidification to acid precipitation were made in Canada, especially southern Ontario. Smallmouth bass, walleye, white suckers, northern pike, lake trout, lake herring, perch, and rock bass have been eliminated from many of the lakes. These effects were first detected in the vicinity of the Sudbury metal smelters. Increases in lake acidity of more than one hundredfold in the past decade have been observed, and of the 150 lakes surveyed, 33 were classified as "critically acid" (pH less than 4.5) and 37 were classified as "endangered" (pH of 4.5 to 5.5). It has been more recently estimated that 200 to 400 lakes within a 50-mile radius of the smelters contain few or no fish whatsoever.

FREQUENCY DISTRIBUTION OF pH AND FISH POPULATION STATUS IN FORTY ADIRONDACK LAKES GREATER THAN 610 METERS ELEVATION

Surveyed during the period 1929–1937 and again in 1975



Source; Schofield, C.L., "Acid Precipitation Effects on Fish," AMBIO, 1976.

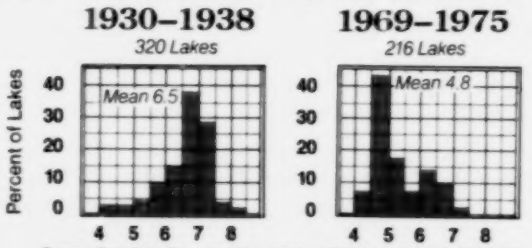
Normal fish development at pH 5.5

Abortive development at pH 5.0

In the United States, similar effects have recently been observed in the Adirondack Mountains where more than half of the remote mountain lakes at elevations greater than 2,000 feet demonstrated pH values of below 5.0; of these lakes, 90% contained no fish. In contrast, between 1929 and 1937, only 4% of these lakes had a pH of under 5.0 or were devoid of fish. While there are numerous other areas of poorly buffered surface waters in the eastern and midwestern United States, up-to-date inventories of fish populations have generally been lacking.

The most common cause of decline in fish populations is failure in the reproductive cycle. Through a series of reactions induced by lake or stream acidity, calcium levels of prospective mother fish are lowered to a point where she cannot produce eggs. When eggs do develop, they may not be passed from the ovary to be fertilized; even when the eggs are fertilized, both eggs and the freshly hatched larvae do not develop normally. Those few fish that do survive continue to be plagued by the acid water, their systems so stressed that their biochemistry is altered. Where there is year-round acidity, the stress is acute. In lakes subject to highly acidic spring thaws, where acids are released in sudden, intense bursts, the already stressed fish tend to die in large numbers.

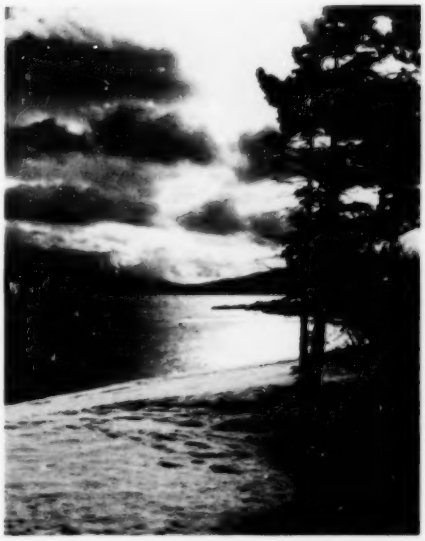
FREQUENCY DISTRIBUTION OF pH IN ADIRONDACK LAKES

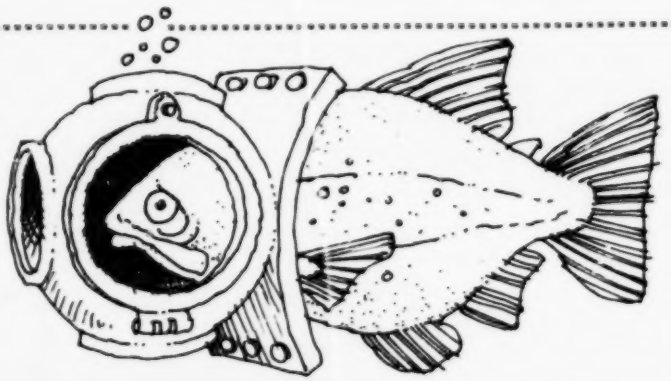


Source; Schofield, C.L., "Acid Precipitation Effects on Fish," AMBIO, 1976.

Precisely what kills these mature fish? It is known that a low pH can lead to improper body salt and calcium regulation in fish, which, in turn leads to altered metabolism of sodium and other elements. It is also thought that indirect effects might be responsible—specifically, the effects of the acids on the fish food and the resulting altered food supply. An examination of the stomachs of 825 perch from 49 different Swedish lakes indicated that shifts in eating patterns did indeed occur, but no conclusive link between food supply and the elimination of fish species was established.

However, a direct link *was* found between fish deaths and some metals. For example, aluminum and manganese become mobile and soluble in soil after an acid rain, therefore, the concentrations of these materials increase in the soils. Runoff and leaching subsequently transfer the metals to the water in sufficient amount to cause fish to die (see box).



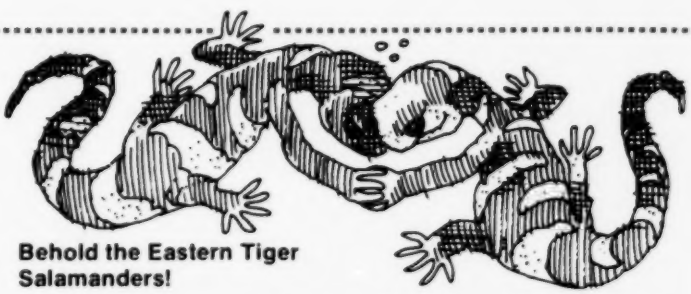


Scientists were puzzled to find heavy trout mortality occurring in lakes whose acidity was inadequate to account for the damage. It was then discovered that there was a "second wave of destruction" in the wake of acid rain. The soil surrounding the lakes reacted with the acid in the rain to release large quantities of aluminum into the lakes. Aluminum in that form is deadly to fish. The poisoned runoff moved rapidly across the water surface. In deeper lakes with good oxygen supplies, fish could find refuge at the bottom. In shallower lakes, however, fish were caught in a deadly trap. They had the choice of dying from lack of oxygen at the bottom, or from acids and aluminum at the top.

Another metal, mercury, may produce lethal effects as a result of acid rain. As lakes acidify, mercury goes into solution as highly toxic organic methyl mercury. A clear correlation exists between the acid level of lake and the mercury levels of its fish; the more acid added to the lake's waters, the more mercury in the fish, up to the point where the fish may begin to die. Those fish that survive present a clear danger to man—mercury, at even extremely low levels can be lethal once it is introduced into the food chain and consumed by humans.

Overall, the prognosis for fish in these acid lakes is not good, for even the most resistant species are affected when the pH drops below 5.0. Presently, scientists are at work developing a strain of acid-resistant fish to replenish the depleted Adirondack lakes. But *how* resistant? And what will they eat? The real answer it would seem lies not in making a "better" fish, but in diminishing the amount of acid pollutants in the air that result in this decimation of fish populations.

Far more than the lives of fish, of course, are at issue in these aquatic environments. Acid rain has interferred with the reproduction of frogs and salamanders. Dense mats of peat moss, ordinarily a land plant, are turning up on the bottoms of highly acidified lakes. This may upset nutrient balances between the lake's water and bottom. Algal communities in lakes with a pH of under 6.0 contain fewer species, with a shift to more acid tolerant forms. The growth of rooted plants and the rate of decomposition of organic matter is being reduced by acids; there are more fungi, less bacteria, and fewer species of aquatic invertebrates to be found in both the sediment and in the water column. Thus, acid rain presents a threat to much if not all of the aquatic community. Through many complex and subtle mechanisms, acid rain is already changing a significant and important portion of our environment.



Behold the Eastern Tiger Salamanders!

They emerge on early spring nights to woo and be wooed in nearby ponds. Sometime later the female lays a mass of eggs surrounded by a jelly-like substance. The eggs hatch in some 12 to 18 days. Adulthood takes two years to reach.

In acid ponds, however, the Eastern Tiger Salamander's nuptials often go unrewarded and populations are dwindling. The jelly-like substance surrounding the eggs absorbs acid water and embryo development is impaired.

In laboratories, mortality was 0.6% at a pH of 7, 0.9% at a pH of 6, 44% at a pH of 5.5 and over 65% at pH values lower than 5. Embroyos die at late stages of growth, with the greatest number of deaths occurring at the outer portion of the egg mass. Eggs in the center were protected from acids by their outer neighbors. Further laboratory testing of field-laid eggs demonstrated almost identical results, pointing to the conclusion that acid precipitation is definitely the factor in the Eastern Tiger Salamander's demise.

Through the realization of the causes of these small deaths comes the recognition of the pervasiveness of acid rain on unprotected animal life.

Effects on Soil Systems

Beyond the food provided them through photosynthesis, plants must obtain mineral nutrients to grow normally. These substances are taken up from either the soil by roots or from precipitation and dry deposition on leaves. Animals also require mineral nutrients and obtain them at salt licks, in drinking water or by eating plants or other animals.

Mineral and chemical nutrients enter the soil in two ways: by weathering from parent rock or by wet and dry deposition from the atmosphere. Once in the soil they are continuously recycled through plants and animals back to the earth in the form of dead organic matter—a constant process of regeneration.

Acid Rain Effects on Plants and Soil

- Lesions reduce growth.
- Litter accumulates, and bacterial decomposition is inhibited.
- Nitrogen fixation is inhibited.
- Calcium, magnesium, and potassium are leached from the leaves and soil.

Often these nutrients are not in forms usable by plants, and chemical transformations must take place to make them so. For example, in order for plants to get at the nutrients contained in dead organic matter, the material must first be broken down, usually by bacteria and fungi. A key nutrient, nitrogen, is partly replenished in the soil by microorganisms, which extract it from the atmosphere.

Acid rain may disrupt this system of soil regeneration in two fundamental ways. First, acids in rain could suppress the decay of organic matter and the formation of nitrogen-fixing products on the roots of legumes such as soybeans. Blue-green algae, another nitrogen-fixing organism, ceases to function below a pH of 6.

Second, acids in rain may affect the storage function of soil. Valuable nutrients like calcium and magnesium are bound to soil particles and thus are protected from being rapidly washed into groundwater. Normal rain can break these bonds to leach the soil of these nutrients; acid rain, however, might greatly accelerate the process and thus reduce the mineral stores of soils.

In the already nutrient-poor woodland soils of Sweden, scientists have observed a reduction in forest growth which they attribute to continued leaching of calcium and other nutrients from the soil by acid rains. Similiar studies of North American forests, however, are inconclusive. Continued acid rain could damage the properties of soils, which in turn may eventually reduce plant productivity, thus leaving forests without the food necessary to grow as quickly and as vigorously as they have in the past. The extent to which this could impact our forest products industry—paper, or wood for homes, for example—is just not known.

Acid rain also causes plants to take up and hold greater amounts of potentially toxic substances. It has been demonstrated that leafy plants (such as lettuce) exposed to acid precipitation retain an increased amount of cadmium. In this case, even if productivity is not affected, the plants may be unmarketable and food supplies diminished.

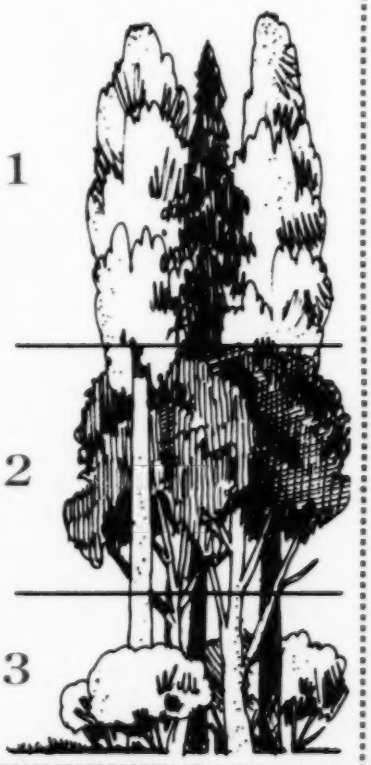
Acid Rain and Vegetation

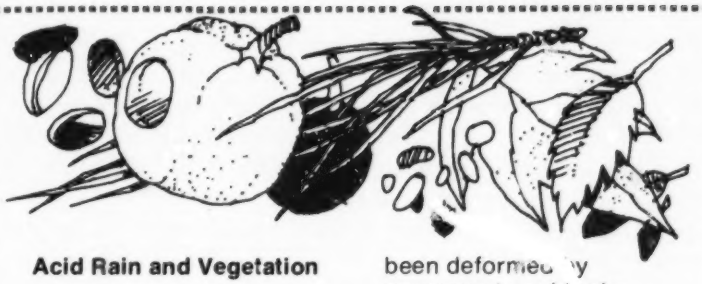
Acid rain could have direct impacts on plants. It may affect young growing tissues and the process of photosynthesis. Plants require their embryonic tissue throughout their lives for the formation of new leaves and buds. When tissues are damaged, a plant's developmental power is diminished, gross deformations occur (much like birth defects), vitality is sapped, and chances for survival are lessened.

"Meanwhile, Back in the Forest."

In forests, raindrops wash over three tiers of foliage before reaching the soil. What is the effect of acid rain on this foliage?

Visual signs of injury occur on plants where pH values are 3 or less—brown pockmarking after a few hours and the pitting of both faces of the foliage after a day. These leaf lesions reduce the area for photosynthesis, limit leaf growth, affect root growth, decrease soil respiration and affect germination of conifer seeds. At intermediate pH levels where there are no visual signs of damage, however, significant reductions in the weight of the leaves point to other forces at play, although it is not yet clear what forces and how strong they may be.





Acid Rain and Vegetation

While some plants thrive in acidic conditions, many others do not. Early in this century plots of timothy grass were treated with sulfuric acid solutions in a pH range of 2.2 to 3.7. At the end of three year's time, the grass exposed to the least acidic treatments showed a decline in productivity. The grass exposed to the most acidic treatment was dead.

More recently:

- Western pines sprayed with sulfuric acid at a pH of greater than 4.0 grew needles half as large as control pines, thus severely diminishing their photosynthetic capacity.
- Yellow birch seedlings 2 to 5 weeks old subjected to a misting with sulfuric acid at pH 3.0 showed the younger plants to be more susceptible to damage than the older. More mature yellow birches have also been deformed by exposure to acid rain.
- Tomato plants in Hawaii exposed to low pH rain showed decreases in pollen germination and pollen tube growth. Lower quality and quantities of fruit result.
- Kidney beans, pinto beans, sugar maple and yellow birch foliage demonstrated pockmark acid lesions when misted with pH 3 solutions. The threshold for bush bean foliage was pH 2.5. Studies of the yields for these plants, however, showed mixed results.
- Christmas tree farms in West Virginia, downwind of the Kyger Creek coal-fired plant in Ohio, have suffered extensive damage. Acid rain or dry deposition has been implicated, and the disease afflicting the trees has been duplicated in at least two independent laboratory studies using sulfuric acid mists.

Even more important, however, are the possible effects on photosynthesis caused by acid rain. Photosynthesis is the process by which plants convert sunlight into carbohydrate foodstuffs. It is the chlorophyll in the plant that is charged with the task of capturing the sunlight. Research has shown that chlorophyll taken from plant tissue and placed in an acidic environment below pH 3.0 becomes bleached and is no longer capable of performing its functions. It has not yet been determined, however, whether chlorophyll in the plant will react in a similar manner.

A second influence of acid rain on photosynthesis has been definitely demonstrated—certain plants have shown a clear and significant reduction in carbohydrate production as a result of being exposed to acid. A decrease in carbohydrate producton can result in alteration of those parts of the plant that are organs of carbohydrate storage—seeds, fruits, roots, tubers, etc., which are those plant parts most often used for food.

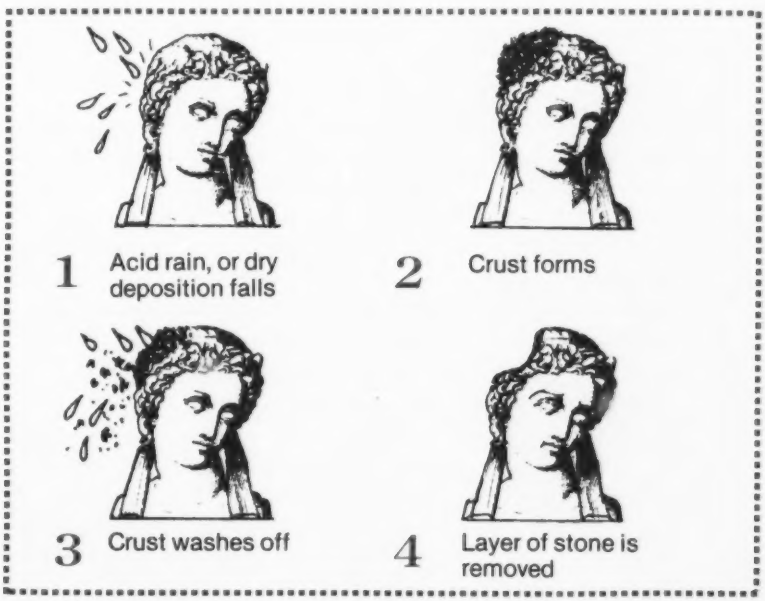
But, not all acid rain effects on vegetation have been deemed destructive. It is known, for example, that nitrogen and sulfur in precipitation can, in limited concentrations, be a beneficial nutrient to some ecosystems. In fertilized agricultural systems the nitrogen might only be equivalent to a small part of the amount assimilated annually, but in pristine forests and in low-organic-content lakes, the nitrogen input from acid rain might represent a significant amount of the total nitrogen required. In fact, in a typical loblolly pine forest in the southern United States, about 40% of the nitrogen comes from the atmosphere.

Acid Rain and Man-Made Objects

Sandstone sculptures erected in Germany in 1702 and photographed in 1908 showed no noticeable deterioration, although the sculptures were over two centuries old. By 1969, however, they were substantially eroded. The interactions between the statuary and air pollution (SO_x, NO_x, acid rain and dry deposition) are thought to be chiefly responsible. Why?

When stone weathers, atmospheric gases dissolved in water or water vapor react with the stone's surface to form a chemically active solution. This solution and the products it forms then either seep into the stone or mix on the surface with environmental soot to form an ugly crust. When the crust is washed away by precipitation it takes a layer of stone along with it. Statues lose their detail and stone buildings are sapped of their structural integrity.

This weathering process is greatly accelerated when the atmosphere contains SO_2 or NO_x and rains are acidic. The SO_2 transforms calcite in the stone into gypsum, which is much more soluble in water. The resulting black sulfate crust—a mixture of calcite, gypsum, fly ash, silica and other pollutants—is then easily washed away by an acid rain and fresh stone is laid bare for further attack.



A link between corrosive damage to steel and SO_2 has also been established. In a recent study, different types of steel were exposed to a variety of pollutants for between 4 and 64 months. The results indicated the presence of SO_2 as the major cause of corrosion. Even zinc, long used in galvanizing to protect metals such as steel from corrosion, has itself been demonstrated to fall victim to industrial air pollution where chiefly sulfates work to destroy its protective covering.

Paint manufacturers have also acknowledged problems caused by acid rain in many parts of the country. Industry spokesmen attribute the problem directly to the chemical fallout of sulfuric acid. Oil-based and automobile finishes have been demonstrated to be particularly vulnerable.

Acid Rain and Effects on Humans

The direct biological effects of acid rain on humans have yet to be established. Some experiments investigating lung responses to acids are currently underway to determine the human body's tolerance to the effects of acid mists. And there are other questions: What about acid rain and effects on human skin or hair? At what pH level do we feel the acid? If acids cause burns on leaves at pH 3, what pH level will cause burns on humans? Most environmental health scientists believe that we are more threatened by the pollutants we breathe than those that rain down on us.

The heavy metals released by acid rain, however, do present a potential threat to human health. Recently researchers at Colorado State University and the University of Southern Florida detected minute amounts of mercury compounds in rainfall which could, when the rain is too acidic, be converted into toxic methyl mercury.

Furthermore, it is thought that as drinking water reservoirs acidify, concurrent increases in heavy metal concentrations may exceed public health limits. In New York State, for example, water from the Hinckley Reservoir has acidified to such an extent that when the water comes in contact with household plumbing systems, lead from soldered joints passes into the water at concentrations that exceed the maximum levels recommended by the New York State Department of Health.

Costs of Acid Rain

Today the problem is still too elusive to quantify; there are no hard dollar figures. The economic data on the amount and extent of damage by acid deposition is very much needed. Some important questions:

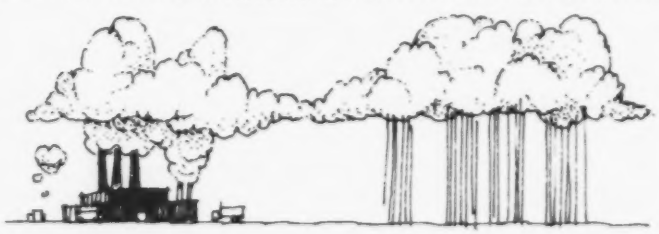
- How much will it cost to clean and preserve the statuary and the buildings already weakened or marred by acid rain?
- How much of the tourist industry has been lost in the "forever wild" Adirondacks? How many related industries suffer? What other areas of the country are vulnerable?

- How much has acid rain already depleted the soil of nutrients? Which crops will suffer? Which farmers? Which related industries?
- Can the forestry industry anticipate a steady decline in the rate of forest regrowth and general forest productivity? What about the price of paper? How will housing starts be affected? Housing prices?
- How seriously are the life spans of cars and homes diminished by sustained acid rains?
- Will our food supply be diminished in the future?
- What will be the sustained loss to the sport fishing industry in the higher elevations most affected by acid precipitation?
- What is the value of a child catching that first lake trout? How shall we value his or her disappointment when fish can no longer be taken from a lake?

Indeed, we do not yet know what will be lost and what the costs will be. Nor do we yet know the most economically sound manner of dealing with the problems caused by acid rain.

THE SOURCES

Acid concentrations in rain vary considerably in the U.S. In the Northeast, sulfuric acid accounts for 65-70% and nitric acid 30-35% of total acid in rainfall; near Denver, sulfuric content is around 10%, while the nitric acid contribution soars to 80%. Both acids result from the by-products of the combustion of coal, gasoline, and other fossil fuels. The primary purpose of this combustion is for energy; the primary locations of this combustion are in stationary sources such as electric utilities and in mobile sources such as cars and trucks.

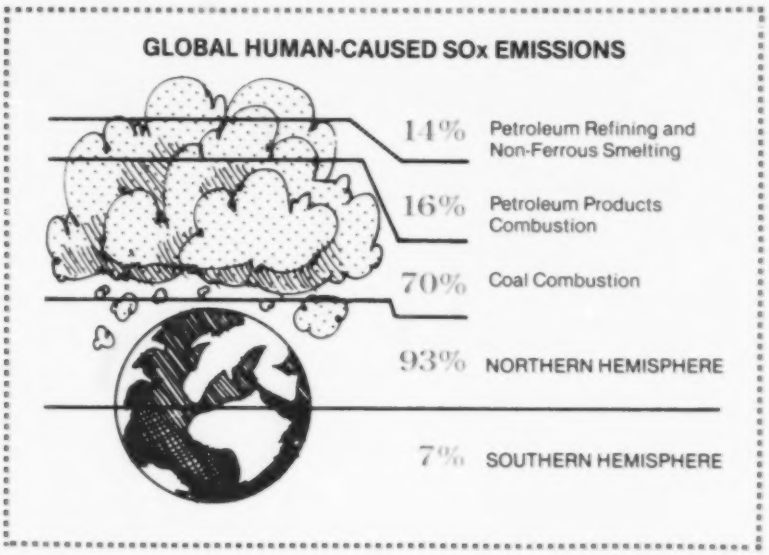


Acid Rain Analysis

If you were to analyze a single sample of even highly acid rain, you would be reassured to find that it was almost totally water. You'd also discover that the actual acid components of the rain were truly minute, even relatively weak. However, the amounts and concentrations of acids we detect and measure are far greater than those acids that occur naturally on the earth's surface. Their existence then leads to a single and obvious conclusion: these acids *are* the leavings of some less than natural phenomenon. That unnatural phenomenon is, to a great extent, the combustion of fossil fuels.

The major man-made sources of SO_x and NO_x are largely upwind of affected areas, and analyses of air-mass trajectories have demonstrated a high correlation between acid rain and storm tracks that have passed over areas where high levels of combustion take place. Ironically, actions taken to reduce local pollution problems from this combustion (e.g., tall stacks) may have also contributed to the acid rain problem. In the mid-fifties, for example, when smog killed thousands in England, tall stacks were built by polluters. The English air cleared but acid rain problems in Scandinavia and Western Europe worsened.

The lessons: Without a clear and complete understanding of how pollution spreads, new problems can be created as old ones are solved; and, changing the distribution rather than the amount of pollution may just shift the problem from one location to another.

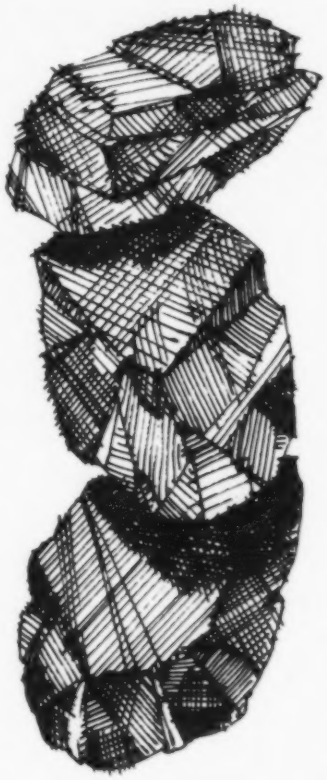


SO_x—How Much, Where, Why

Estimates of total global annual emissions of sulfur, the major acid rain constituent, vary widely, ranging anywhere from 140 million metric tons to 220 million metric tons. Estimates also vary between those man-made emissions from stationary sources and those from mobile and miscellaneous sources. Furthermore, the literature cites some figures for SO_x—the total sulfur oxide category—while other figures refer only to SO_2, the most common oxide (95-98%) resulting from the burning of fossil fuels. Consequently, information based on the estimates is often disparate and confusing. The following numbers, nevertheless, represent a certain consensus in the scientific community.

Between 25% and 50% of total global SO_x emissions released into the atmosphere annually are man-made. Over the Earth's land masses, however, these man-made sources may account for more than 50% of the total annual sulfur released. Of these emissions, 70% result from coal combustion, 16% from petroleum products combustion (primarily residual fuel oils), with the remaining 14% accounted for by petroleum refining and nonferrous smelting.

Man-made SO_x emissions in the United States during 1977 totalled 27 million metric tons. Of that amount, 75% originated east of the Mississippi River, and of that, 92% was emitted in the vicinity of the Ohio river valley as a result of fossil fuel combustion. Of the 25% emitted west of the Mississippi River, fuel combustion was responsible for 38% while industrial and mining and smelting processes contributed the remaining 62%.



A Coal is a Coal is a Coal. Or is It?

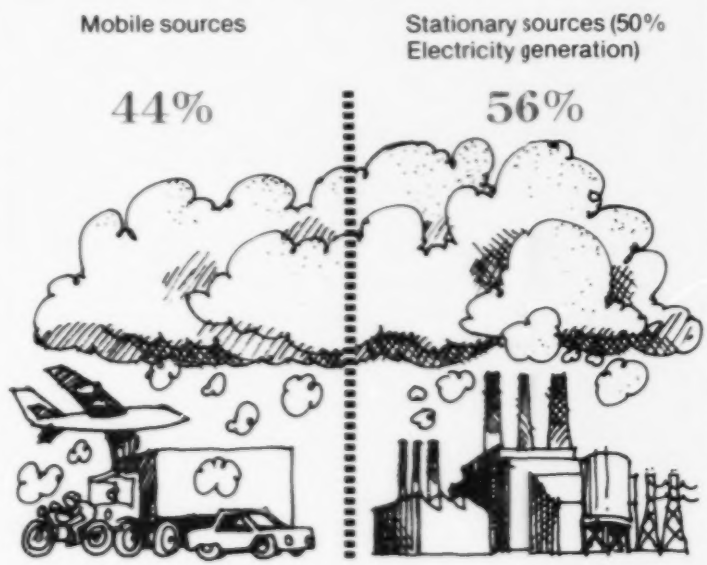
Part of the problem posed by an energy program that depends on America's plentiful coal supply is that there is no "typical" coal on which to base combustion technology or controls. Each region's coal varies widely in heat value per ton, and moisture, ash, and sulfur content. Many Western coals, for example, are lower in sulfur content than Eastern coals. But they are also lower in heating content. Thus, more Western coal has to be burned to create the same amount of heat.

But, those coals most economical to burn to reach a desired degree of heat may not be the ones which will produce the least amount of sulfur in the air and acid in the rain.

NO_x—How Much, Where, Why

The same cautions that apply to the quantifying of SO_x emissions also apply to NO_x only more so. Overall emissions figures for NO_x (man-made *and* natural) are difficult to come by and are often widely disparate. Estimates of the human contribution to global NO_x emissions range from a small percentage to as much as half. It must be remembered, however, that human NO_x emissions are highly concentrated at specific locales whereas natural sources (e.g. decaying matter) are widely dispersed. The United States contributions to worldwide man-made totals during 1977 was approximately 23 million metric tons, again, mostly from the combustion of fossil fuels. There is some disagreement about whether the major NO_x sources are stationary (industrial and utilities) or mobile (cars and trucks), however, the best available figures show that of the U.S. total, approximately 56% of NO_x emissions result from stationary fuel combustion, one half of that from the generation of electricity. The balance resulted mostly from the exhausts of cars and trucks.

In the future, it is estimated that stationary source emissions could double with the increased use of coal for industrial power generation. As it is, NO_x emissions have greatly increased in the last twenty years thus the role of NO_x in the overall acid rain problem has also been on the increase. The reason? Adequate alternate fuels or control measures for stationary combustion sources have been available only for SO_x and not for NO_x emissions. Thus, while many large operations show a decrease of sulfur emissions, NO_x levels are maintained, resulting in a change in the nature of air pollution and of acid rain. And while man-made NO_x emissions may account for only a portion of total global emissions, an important footnote to any NO_x emission discussion is that in a nationwide study of precipitation chemistry, it was found that the nitrate components of acid rain were almost *entirely* the result of human activity.



TOTAL MAN-MADE NOx EMISSIONS IN THE U.S. IN 1977

Controlling the Sources

After all the effects are measured and all the logistics and costs of acid rain "cures" considered, it appears that the only truly practical approach to the problem lies in reducing SO_x and NO_x emissions. Many innovative schemes have been suggested, from altering production and combustion to recovery and conversion of sulfur. There are studies underway to estimate the costs of various ways to reduce SO_x and NO_x emissions. These costs, of course, must be weighed against the costs of damage due to acid rain which are now only beginning to be understood.

Currently, there are three general options for the further reduction of many SO_x and NO_x emissions. Some are costly, others not.

Energy conservation resulting in reduced fuel consumption. Conservation via more efficient fuel use and through improved thermal insulation, etc.

Desulfurization and denitrification of fuels or stack gases and increased use of fuels naturally low in sulfur content or use of technologies that reduce emissions.

Substitutions for fossil fuels by other alternatives.

Conservation, however, may achieve only slower emissions growth rates and low-sulfur fuels are in short supply. Desulfurization and use of low-NO_x-producing technologies are viable control options now and will probably continue to be for some time; substitutions of energy forms are also future solutions to problems posed by SO_x and NO_x emissions.

SO_x Control

A number of techniques to reduce SO_x emissions are already on the commercial market or are in developmental stages. These techniques are categorized by the stage at which they occur in the energy-production process:

- Pre-combustion—here the sulfur content is removed before the fuel is burned; techniques include coal cleaning, coal gasification, and desulfurization of liquid fuels;
- Combustion—the sulfur content is removed during combustion, as in fluidized-bed combustion;
- Post-combustion—sulfur emissions are removed after combustion, as in stack or flue gas desulfurization systems or scrubbers.

Some of these techniques such as coal cleaning and flue gas desulfurization are in full scale use, while others such as fluidized-bed combustion are still being tested in small scale applications. The future of SO_x control from traditional fuel sources lies in the perfection of these techniques.

NO_x Control

For reducing NO_x emissions from stationary combustion sources, the only practical means commercially available in the United States today involves modification of furnace and burner design and/or modification of operating conditions. The modifications generally attempt to reduce the combustion temperatures because at lower flame temperatures less NO_x is formed. The combustion modification techniques now available include staging combustion, precisely controlling air, injecting water during combustion, recirculating flue gases, and/or by altering design of firing chambers.

Mobile combustion sources of NO_x are currently being reduced through a variety of approaches. To date the primary technique for reducing automobile NO_x emissions has been by lowering combustion temperatures in the engine. Today, however, most attention is being focused on catalytic removal of NO_x from exhaust using a 3-way system that reduces carbon monoxide, hydrocarbons, and NO_x simultaneously.

THE LEGAL ISSUES

The long-range transport of acid rain constituents across state and national boundaries presents a tough and challenging legal problem. Historically, most state and federal laws regulating SO_x and NO_x emissions from stationary sources assume that a cause and effect relationship can be established between emissions and pollution, i.e., that pollution in a locale can be traced to a specific emissions source in the same general locale. Local laws with local provisions for enforcement do not take into account the damage caused in states (or countries) hundreds of miles downwind of pollution sources.

The existing Clean Air Act is structured around a similar cause and effect supposition that air pollution can be related to a particular source or to a well defined group of sources. But, in the case of acid rain, there is no clear cut relationship between specific emissions and the acid rain. That is, even though the types of emissions that lead to acid rain are known, it is currently not possible to accurately trace individual emissions that cause acid rain back to their origin.

How, then, is this regional air pollution to be controlled? What is the best control strategy? And what is the appropriate legal mechanism to use? These are some of the key questions with which EPA and other environmental regulatory groups will be grappling for the next few years.

The Clean Air Act has, in recent years, evolved to address the interstate problem of pollution. In 1970, the Clean Air Act gave individual states primary enforcement responsibility. Each state was required to set up State Implementation Plans (SIPs) with emissions limitations sufficient to meet national ambient standards. States, however, were responsible only for controlling pollution within their own borders. For this reason, it is now common to find emission limitations of one state to be more lax or stringent than those of a neighboring state. The 1977 Clean Air Act amendments added requirements that SIPs contain provisions prohibiting any source in the state from preventing attainment or maintenance of a national standard in another state or from interfering with another state's efforts to prevent deterioration of air quality or to protect visibility. These provisions, however, still rely primarily on the state-based SIPs for enforcement. Any given state is only able to enforce its SIP requirements against sources within its own boundaries. The 1977 amendments also provide that affected states can petition the EPA Administrator to control pollution. The major problem facing EPA, however, is how to demonstrate that one or several out-of-state sources are responsible for impermissi-

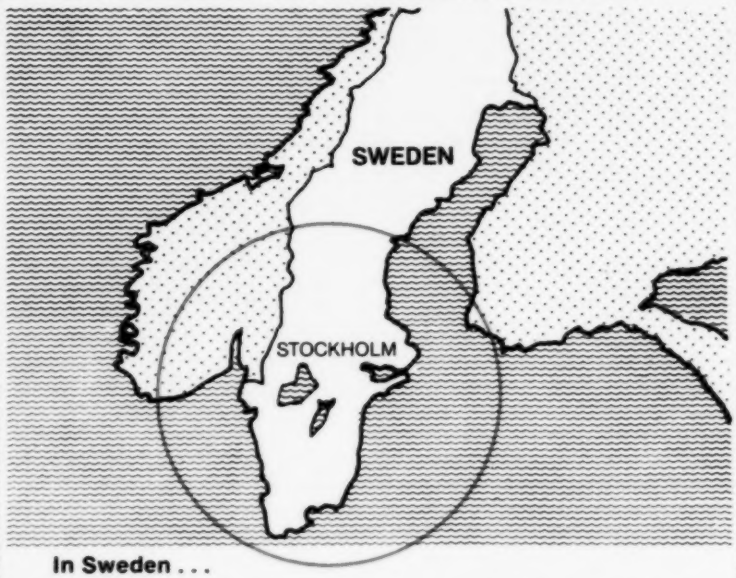
States Take Action

In 1979, New York State, along with other states protested a proposed relaxation of emission limits pertaining to two Ohio river power plants. In the protest, a New York official asks that air be regarded as "a flowing river which can transport contaminants from one part of the nation to another. Airshed boundaries must be reevaluated to make sure all states live up to the same clean air goals."

ble air quality violations. Several questions arise concerning such a demonstration. For example, how can the demonstration be made? Will the demonstration withstand a scientific and legal challenge? And isn't it possible that the effects experienced in the Adirondacks are the cumulative effects of emissions from a number of sources in a number of states and nations? The demonstration, in any event, is hard to make. If an acceptable demonstration is made, however, some action must be taken against the polluter.

To control acid rain EPA must determine how to best use the existing mechanisms of the Clean Air Act in order to develop a control strategy that will deal effectively with interstate pollution impacts.

One possibility is better monitoring of SO_2 emissions, which will permit improved enforcement of emissions limitations. Another possibility is establishing federal regulatory requirements for review of interstate impacts of SIP provisions. Yet another option is developing national ambient air quality standards for nitrates or sulfates, two precursors of acid rain. However, it is not clear if there are sufficient scientific data upon which to base such standards. Moreover, even if data were available, standards for these pollutants would have to be established through the lengthy standards-setting process. Estimates are that it would take five to ten years before any emission reductions could be achieved. A fourth option is for EPA to establish new source performance standards for pollutants for which EPA has not set ambient standards and then establish control requirements for emissions of these pollutants from existing sources. In this way, existing sources of emissions of total sulfur, a pollutant which includes sulfur dioxide and for which EPA has not set ambient air quality standards, might be regulated. EPA is reviewing these and other options to determine which are most appropriate to address the acid rain problem.



In Sweden . . .

Researchers have calculated that 70% of the sulfur in the atmosphere in the southern part of the country comes from human activity . . .

. . . and 77% of this sulfur, it is thought, comes from sources outside Sweden.

The Clean Air Act deals with the question of international air pollution. It permits the Administrator of EPA to trigger a revision of a State Implementation Plan if the Administrator or Secretary of State has reason to believe that emissions in a state cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare in a foreign country. The plan must be revised to the extent it is inadequate to prevent or eliminate the endangerment. A reciprocity clause limits the section's application to those foreign countries that have given the United States essentially the same rights of pollution control as the United States has given these countries under the international air pollution provision of the Clean Air Act. In addition, through agencies like the United Nations Economic Commission for Europe (ECE) and bilateral negotiations, the problems caused by transboundary air pollution between the United States and Canada may be resolved.

EPA AND ACID RAIN RESEARCH

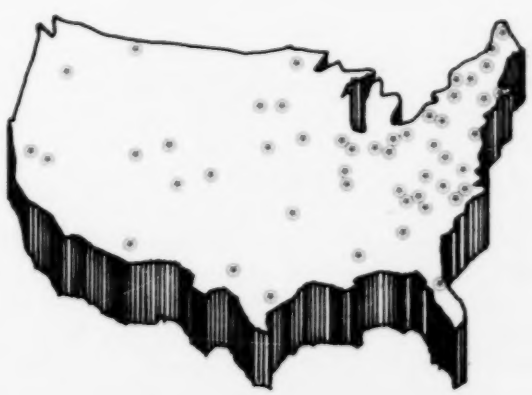
Acid rain research is presently being conducted by many government agencies and by private industry. Those directly involved include in addition to EPA: the Electric Power Research Institute, the Forest Service, the Fish and Wildlife Service, State Agricultural Experiment Stations, the Geological Survey, the National Science Foundation, the National Oceanic and Atmospheric Administration, the Department of Energy, the Tennessee Valley Authority, and many research institutions, universities, and industry groups.

Within EPA, two overall themes provide a framework for ongoing research and development. One, EPA must communicate to Congress and to the public the effects of acid rain, with special attention paid to the ecologic and economic consequences of continued high levels of acid precipitation. Two, EPA must continue to generate additional information that can be used to develop air quality control strategies and options.

In his second environmental message, President Carter identified acid rain as a major global environmental problem and proposed a multiagency 10-year plan for research into the subject. The plan establishes an Acid Rain Coordinating Committee consisting of seven federal agencies. The Committee is co-chaired by representatives from the U.S. Department of Agriculture and from EPA.

The 10-year plan is for vital research; vital because today acid rain knowledge is insufficient to provide a thorough understanding of the nature of the problem. What *is* known, however, is that acid rain is a global problem that results in a key inequity: the populace of one state or country enjoys the economic and industrial benefits that are derived from energy production, while those in other locales and not benefitting must pay the price of the consequent pollution. As international boundaries are crossed, the resolution of such inequities grows more and more complex.

Currently, EPA is working together with many other agencies to gather and interpret the scientific information necessary to demonstrate the impacts of acid rain and to establish which controls would be most effective in alleviating these impacts. These programs are designed to: (1) monitor the sources and deposition of acid-causing pollutants, (2) discover and model the means of transportation in the atmosphere including the chemical reactions that take place in the air and (3) determine the environmental effects that are caused when acids rain upon plants, animals, property and people. EPA has published a summary of its acid rain research program (see Research Summary Acid Rain, EPA-600/8-79-028).



NATIONWIDE ACID PRECIPITATION MONITORING STATIONS

EPA's function in future acid rain research will be to ensure coordination among federal agencies and state and private researchers; EPA will also help to plan the roles for research and for amelioration and regulatory policies. Additionally, EPA's technical role will be to collect data, conduct experiments, and arrive at the scientific conclusions needed for future acid rain decisions.

President Carter also spelled out the need for public participation in the acid precipitation issue when he directed the Acid Rain Coordinating Committee to "actively solicit public involvement in its planning and reviews of the research results of the Committee's program . . ." This directive will help to ensure that future research directions by EPA and other agencies will speak directly to the needs and best interests of the American people. It also serves as an impetus to EPA to communicate its research information in a manner that will support public debate about this important problem.

Potential Research Directions

Future research on acid precipitation and its effects in the United States must be built upon past data and on previous efforts to study the problem both in North America and abroad. Past EPA research relevant to acid rain includes programs to help discern how atmospheric sulfur products move long distances, technology development programs to devise means to control the sulfur at the source, investigations into the effects of acid rain, and establishment of networks for rainwater collection and analysis to monitor pollution dispersion.

Many specific decisions about research and development efforts will need to be made in the future. Building on already available data some potential research directions are:

- Investigation of the causes of the widespread acidification of rain in the eastern United States over the past 20 years;
- Exploration of the rate at which rainfall is becoming more acid and the rate at which the problem is becoming geographically more widespread;
- Examination of the quantitative contributions of various acids, especially nitric acid, to the overall acidity of rainfall;
- Investigation into the relative extent to which the acidity of rainfall in a region depends on local emissions of sulfur and nitrogen oxides versus emissions transported from distant sources;
- Survey of the continent-wide extent and severity of acidification of aquatic and terrestial ecosystem;
- Collection of baseline data to establish the point of departure for monitoring and measuring the effects of continued acid precipitation;
- Determination of the pH tolerance of aquatic organisms, forest and orchard trees and agricultural crops;
- Development of diagnostic tests for acid injury to plants and animals and man;

- Continuation of whole ecosystems studies for further information on nutrient cycling chemical budgets;
- Examination of synergistic effects of pH and heavy metals, disease, etc.;
- Investigation of the mechanism of toxicity of acid precipitation to fish and other aquatic organisms;
- Studies on the impact of acidic snowmelt on stream and lake biogeochemistry;
- Analyses of economic damage to sensitive ecosystems and materials.

ACID RAIN TOMORROW

With oil in short supply in the United States and many of our foreign oil sources becoming less secure and ever more expensive, the rush is on to exploit our national coal reserves. Whatever energy plan is ultimately adopted, it *will* include the burning of coal—and a lot of it. What does this mean to acid rain?

As utilities convert to coal, SO_x emissions could be reduced, remain somewhat constant or increase, depending on a number of variables. The technology exists to burn coal cleanly, and a number of control alternatives are possible, ranging from low-cost coal cleaning to the installation of stack gas scrubbers. Early retirement of existing oil-fired plants and replacing them with new, better controlled, cleaner coal-fired plants would yield a net reduction in emissions.

Today also, a number of oil-fired plants are capable of burning coal. These can be converted back to coal without an increase in regional SO_x emissions provided the best available control technology is applied during the conversion. At today's oil prices, in fact, it is estimated that it costs more to run many existing plants with oil than it would cost to convert them to coal *and* install good pollution control equipment.

Equally important is the question of the nitrogen oxides that will be emitted from these plants—old and new, converted or not—and from cars and trucks in the future that continue to burn fossil fuels. Less is known about NO_x emissions effects, yet, NO_x *is* a key constituent of acid rain. And with increased fossil fuel combustion, and less stringent controls in force than for sulfur, there will probably be relatively more NO_x in our rain in the future.

The future? We have already seen acidified lakes no longer able to support fish populations and other aquatic life. We have seen the faces of buildings and the faces of statues lose their integrity. We have, after all, already witnessed a rainfall in this country of pH lower than 3.0, a rain more acid than vinegar. Without a firm commitment both to developing improved pollution control methods and to applying those methods rigorously, the problems of the past could be a prelude to an acid rain future.

For Further Reading

Research Summary Acid Rain, EPA-600/8-79-028, prepared by the Office of Research and Development/ Environmental Pro'ection Agency (October 1979)

A companion document to this Decision Series report, the Summary offers a complete but concise description of the EPA acid rain research program. The three major program categories—environmental effects, monitoring and atmospheric processes—are described and individual projects are listed.

A National Program For Assessing The Problem of Atmospheric Deposition (Acid Rain), prepared by the National Atmospheric Deposition Program, (December 1978)

A study funded by the President's Council on Environmental Quality, the report summarizes the issues facing researchers and regulators. Background information chapters are authored by noted experts; research programs are recommended. A good source of accurate up-to-date scientific information.

Environmental Effects of Increased Coal Utilization: Ecological Effects of Gaseous Emissions from Coal Combustion, EPA-600/7-78-108, an Interagency Energy/Environment R&D Program Report prepared by the EPA's Environmental Research Laboratory, Corvallis, Oregon (June 1978)

A brief evaluation of air pollution impacts from coal combustion on ecosystems and the environment. Acid precipitation is specifically considered. The report provides a preview of potential effects as more coal is burned in America.

The Multistate Atmospheric Power Production Pollution Study -MAP3S, DOE/EV-0040, prepared by the U.S. Department of Energy, Office of Health and Environmental Research (July 1979)

A very detailed report about work which has taken place to understand the transport, transformation and fate of air pollutants from energy activities. An excellent annotated bibliography covers the literature on the subject.

Proceedings of the First International Symposium on Acid Precipitation and The Forest Ecosystem, prepared by the U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station, (1976)

A collection of scientific papers given at the symposium. Although somewhat dated, many of the controversies that remain today are evident in some of the differences between the papers. Some of the papers are by foreign scientists, particularly from Sweden and Norway.

Scientific Papers from the Public Meeting on Acid Precipitation, by the Science and Technology Staff, New York State Assembly (May 1978)

This set of papers is essentially an information update on acid precipitation. Unfortunately, the general conclusion is that quantitative data are still lacking. The papers are for the most part, short and readable.

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Proceedings: Advisory Workshop to Identify Research Needs on the Formation of Acid Precipitation, EPRI EA-1074, prepared by Sigma Research, Inc. for the Electric Power Research Institute, Palo Alto, California, (May 1979)

A brief review of current information about the formation of acid rain and some recommendations of research needed to gain a better understanding of the problem. Relevant research projects now underway are listed.

Ecological Effects of Acid Precipitation, EPRI EA-79-6-LD, prepared by the Central Electricity Research Laboratories of England for the Electric Power Research Institute, Palo Alto, California, (December 1979)

A set of papers from a small group of scientists who have been engaged in research about acid rain. Uncertainties about current acid rain information are identified and crucial data gaps are pinpointed.

Acid Rain, preprint 3598, by the American Society of Civil Engineers, Environmental Impact Analysis Research Council for their 1979 Convention in Boston, (April 1979)

A collection of six talks given at the Convention. All six are interesting, credible and very readable and give a nice overview of the subject.

Credits for this report:
Richard Laska, Mark Schaefer, Dave Myers, Tom Parker, Bill Wells, Phyllis Dorset, Jean McLean, Ken Altschuler, Marja Wicker, Barry Scott-Walton

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Technical reviews:
Professor Gene Likens, Cornell University; Professor Ellis Cowling, North Carolina State University; Dr. Robert W. Brockson, Electric Power Research Institute; Dr. Gary Glass, EPA-Duluth; Mr. John Backman, EPA-Research Triangle Park; Mr. Danny Rambo, EPA-Corvallis; Mr. Dennis Tirpak, EPA-Washington, D.C., Ms. Lydia Wegman, Office of General Counsel, EPA-Washington, D.C., Mr. Ralph Luken, Office of Policy Analysis, EPA-Washington, D.C.